MODULATED SPECTRAL ACTIVITY (MSA) IMPLICATIONS FOR PLANETARY RADIO SOURCES

James R. Thieman[1], Joseph K. Alexander[2], and David H. Staelin[3]

[1]*National Space Science Data Center,*
NASA/Goddard Space Flight Center,
Greenbelt, MD 20771, USA

[2]*Office of Space Science and Applications,*
NASA Headquarters,
Washington, D.C. 20546, USA

[3]*Massachusetts Institute of Technology,*
Cambridge, MA 02139, USA

Abstract

High time resolution (6–sec) frequency–time spectrograms of radio emission measured by the Voyager Planetary Radio Astronomy (PRA) instruments at Jupiter and Saturn show modulation patterns within the normally diffuse non–thermal radio emissions. The patterns are characterized by distinctive banded structures of enhanced intensity meandering in frequency over time scales of minutes to tens of minutes. This we call Modulated Spectral Activity (MSA). The bands sometimes track each other, similar to harmonic emissions, and at other times drift relative to each other, though crossing of bands is not observed. Plots of single 6–second sweeps from high to low frequencies often exhibit a slow rise in intensity followed by a sharp dropoff for each band as frequency decreases. Both Jovian and Saturnian MSA normally are observed in the frequency range of roughly 0.2–1.3 MHz (i.e. within PRA low band), but similar patterns have been found in Jovian decametric emission above 30 MHz. Both rapid and slow frequency drifts of MSA have been observed from one 6–second sweep to the next. Observed properties suggest a number of constraints on the possible source mechanism. Although aliasing is a possible explanation of some MSA, it is unlikely that MSA is always an aliasing phenomenon since many of the events show a low drift rate for many minutes and any time modulation producing such a drift rate must be very stable in frequency. Properties of the MSA together with the possible implications for the source mechanisms were presented for discussion.

1. MSA definition and examples

The Planetary Radio Astronomy experiment (PRA) aboard Voyagers 1 and 2 provided a wealth of information about the radio spectra of the planets Jupiter, Saturn, and, most recently, Uranus in the frequency range from 1 kHz to 40 MHz. Most of the spectra which have been analyzed and which appear in the literature are the "48–sec averages". For these spectrograms eight 6–sec frequency sweeps of the instrument are averaged together to yield the one displayed sweep representing 48 seconds (see Lang and Peltzer, 1977, for hardware description). Using this averaging method, the usual spectrogram panel can display many hours of data (e.g., one 10–hour rotation of Jupiter, see Warwick, et al., 1981). Some spectrograms have been produced with full 6–second time resolution, especially during the several week periods before and after Jupiter and Saturn encounter. Examination of these spectrograms often shows a modulation of the normally diffuse and slowly–varying emission which is common in the low–band (1kHz–1.3 MHz) frequencies measured by the instrument and which is not apparent in the usual 48–sec spectrograms.

Figure 1 shows four examples of this type of modulation superimposed on the normally diffuse Jovian Hectometric radiation (HOM). This phenomenon we call Modulated Spectral Activity or MSA. MSA may be divided into two types, banded and chaotic. The top panel of Figure 1 shows examples of both types. Banded MSA appears as a distinct modulation pattern consisting of one or multiple tones or bands meandering in frequency and lasting minutes to tens of minutes. Chaotic MSA shows modulation without organized bands, often with multiple modulations for each frequency sweep, but the modulations do not align in frequency as they do in the banded case. Panel (a) of Figure 1 begins and ends with the chaotic form of MSA from approximately 0005 to 0015 and 0050 to 0055 Spacecraft Event Time (SCET) in the frequency range from approximately 0.5 MHz to the upper limit of the PRA low–band measurements at 1.3 MHz. The chaotic form of MSA precedes and follows the banded form occurring from 0015 to 0050. Panel (b) shows a similar banding occurring from 1110 to 1120, but in this case the bands appear against a diffuse emission background. Other weaker and narrower bands appear from 1132 to 1140 and 1149 to 1156. Panel (c) exhibits a few widely–spaced bands from 2115 to 2135. These slowly increase in frequency with time whereas the bands in panel (d) (1925–1945) vary both up and down in frequency.

MSA bands often appear to track each other, but not perfectly. Thus, the spacing between frequencies is not a constant and may increase and decrease within the same event. There is, however, almost never an appearance of a crossing of the bands. One other phenomenon of interest is the apparently simultaneous turn–on of the weak bands beginning at 1149 in panel (b) of Figure 1.

MSA is not confined to Jovian emission. Figure 2 shows four examples of MSA events in conjunction with Saturnian Kilometric Radiation (SKR). MSA is often found at the upper frequency limit of SKR emission and is often weak and single–banded with a hint of multiple bands as in panel (a) from 0945–0955. The frequent appearance of MSA at the top of the emission envelope suggests a generation of MSA as a part of the source mechanism. The other panels in Figure 2 represent examples of multiply–banded events. There does not appear to be nearly as much of the chaotic form of MSA at Saturn as there is at Jupiter.

MSA events are not always confined to the low band of the PRA receiver either. The Jovian Decametric radio emission (DAM) is observed in the PRA high band (1.3 to 40 MHz) and occasionally exhibits MSA–like events. Banded events appear in Figure 3 as single (panel (a)) or closely–spaced dual tones at the upper edge of the emission envelope. In the middle panel the bands extend from 0920 to 0955 at frequencies around 33 MHz. The band–like events which appear like parentheses in the frequencies from 5 to 30 MHz are the well–known Jovian arcs (see Boischot et al., 1981, and references

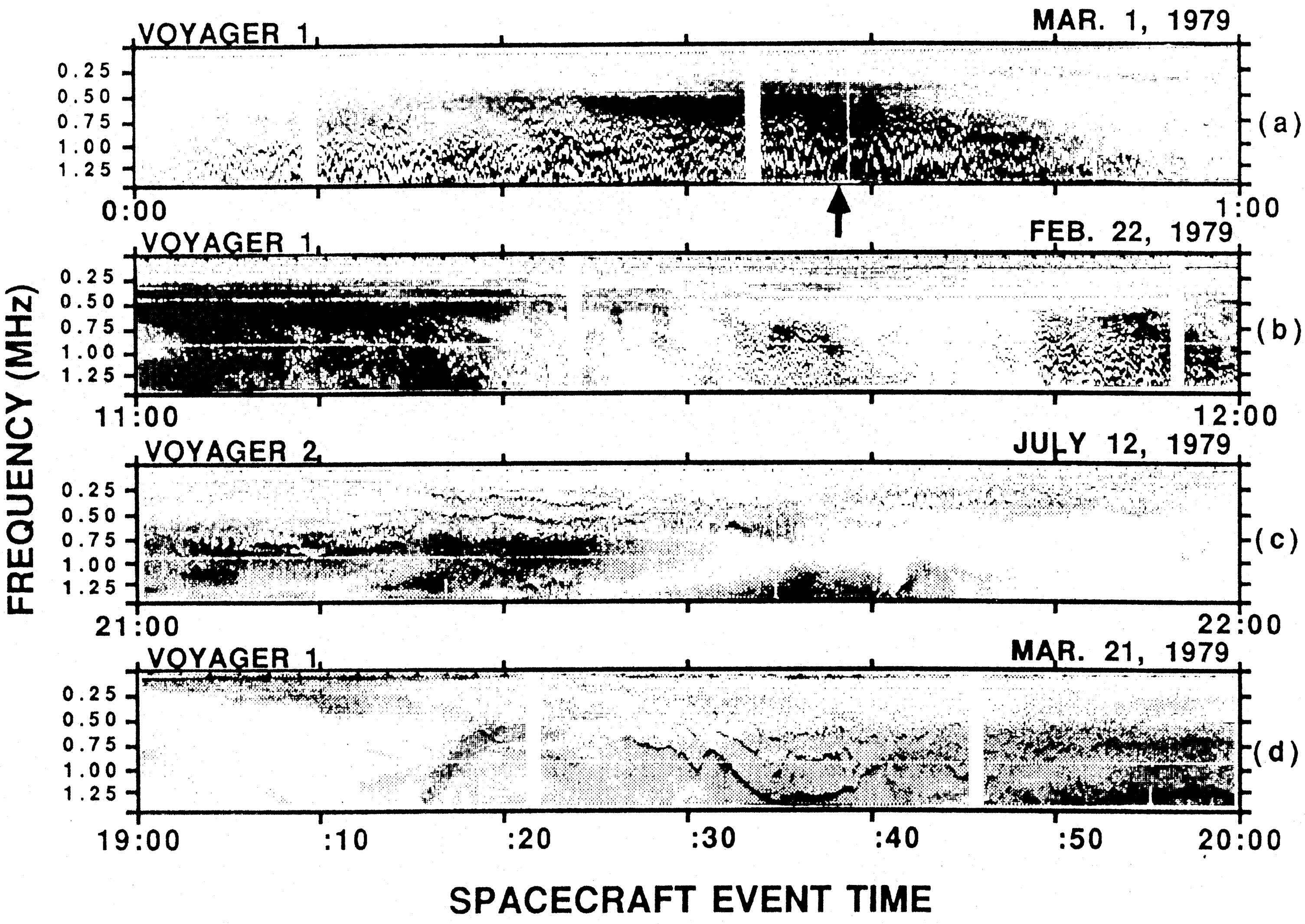

Fig. 1: High time resolution, low–frequency–band spectrograms of Jupiter's hectometric radio emission as measured from Voyagers 1 and 2 showing selected MSA events. The intensity of radiated power is proportional to gray scale darkness. Panels (a) and (b) were made prior to closest approach whereas (c) and (d) represent post–encounter data. The arrow in panel (a) indicates the location of the sweep shown in Figure 4.

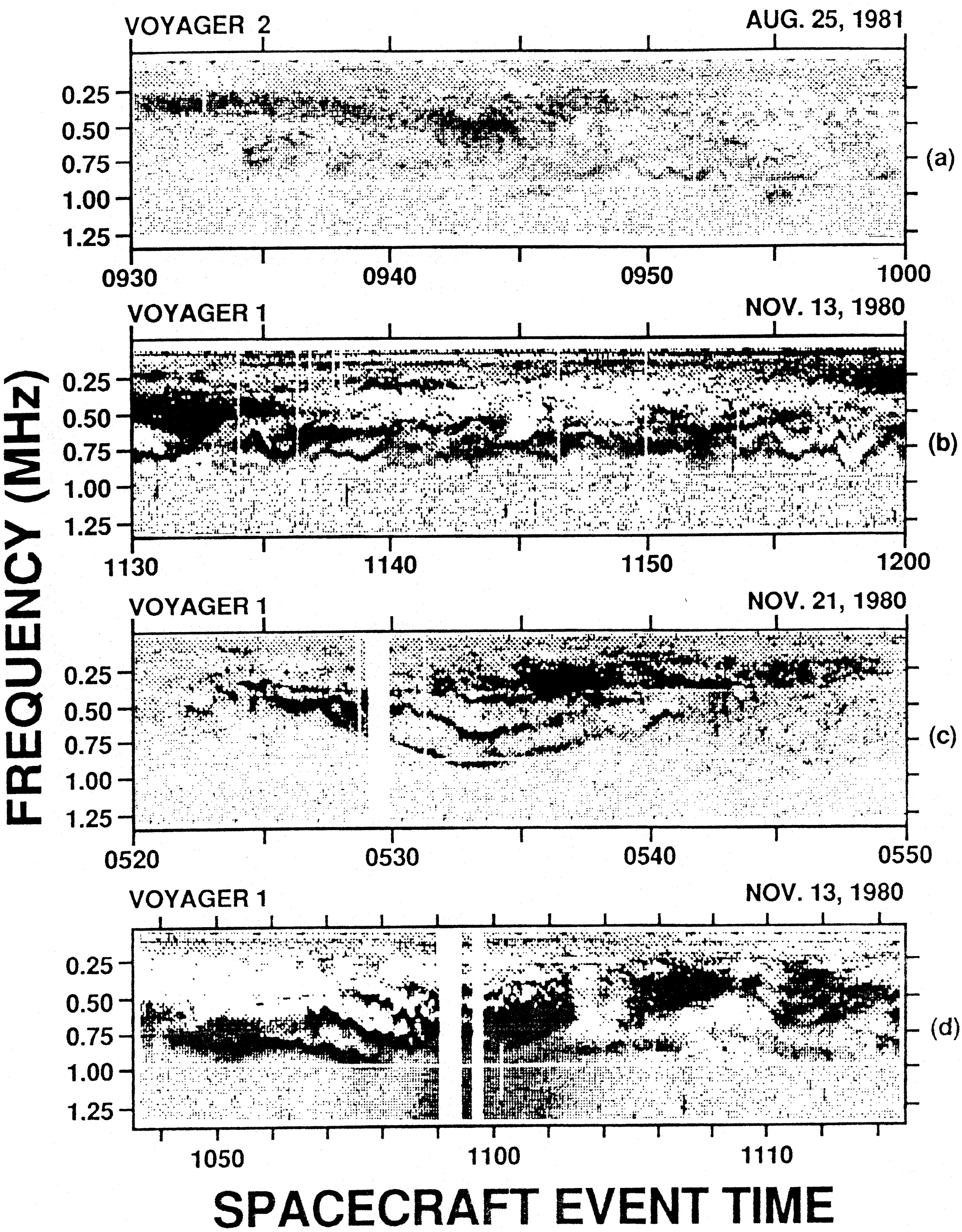

Fig. 2: Same type of spectrograms as in Figure 1 displaying MSA events near the closest approach of the Voyagers to Saturn.

therein) which we consider to be a different phenomenon. The entire bottom panel has the same type of bands drifting down from a maximum frequency of approximately 20 MHz. The events in the two bottom panels have been studied by Leblanc and Rubio (1982), who call them narrow–band splitting events. They usually appear at the upper edge of Io–controlled source B and source C events (see Carr et al., 1983, for details of the radio source nomenclature and the Io control phenomenon). As with MSA in SKR, the upper edge occurrence suggests a relationship with the emission mechanism. The banded events are usually narrowly–spaced dual tones but examples of wider–spaced events have been found. Chaotic–like events may also be observed in the high band and these are often identified with Jovian S–bursts, again in conjunction with Io–controlled emission (Leblanc and Genova, 1981, and Alexander and Desch, 1984).

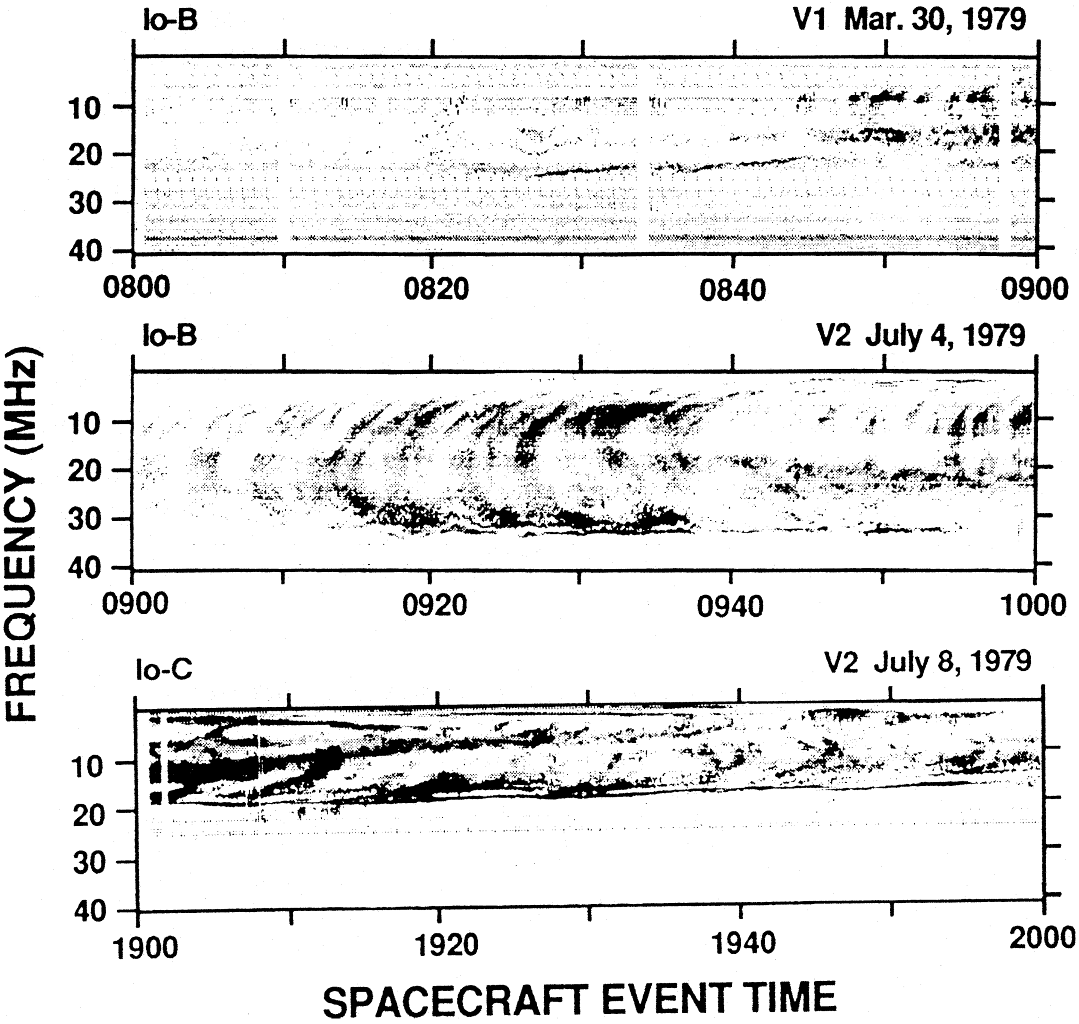

Fig. 3: High time resolution spectrograms as in Figure 1, but from the Voyager PRA instrument high–frequency band, showing MSA events associated with Jovian decametric (DAM) radio emission.

2. Characteristics and constraints

Figure 4 is a plot of emitted power above a fixed background threshold vs. frequency for the 6–second sweep indicated by the arrow in the top panel of Figure 1. Peaks of the MSA bands which are discernible in the spectrogram are indicated by the arrows in the plot. The ten highest frequency channels show alternating increases and decreases in power which are indicative of a polarized emission since the sense of polarization alternates between the left and right–hand senses as the receiver steps through the frequency channels. This alternating variation of power is superimposed on an overall decreasing power level as frequency increases. Nowhere else in the plot is there any clear indication of a polarized signal. In general, the study of MSA events indicates no consistent polarization for the events.

On the other hand, there is a notable asymmetry in the morphology of the band peaks with skewing toward low frequency. Thus the power level drops off more rapidly on the low frequency side of the peak, creating a "sawtooth" pattern. This is quite often observed in both banded and chaotic MSA.

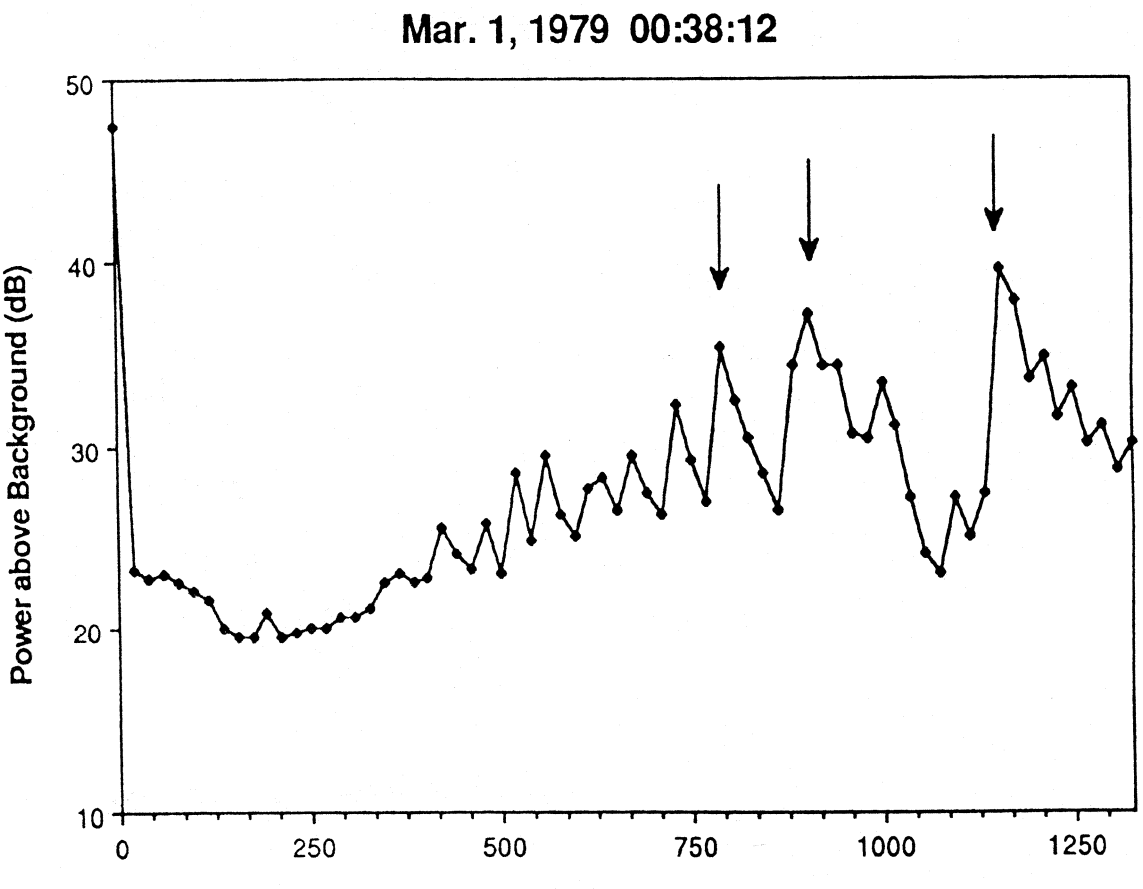

Fig. 4: Plot of HOM power above background versus frequency for the spectrogram sweep shown in Figure 1 (a) by the arrow. Measurements are made at intervals of 19.2 kHz from 1.2 kHz to 1326 kHz with a bandwidth of 1 kHz. The arrows indicate the peaks of bands which are discernible in the spectrogram.

BANDED MSA

PARAMETER	REPRESENTATIVE VALUES		
	HOM	SKR	DAM
BANDWIDTH	60-100 kHz	60-100 kHz	1-2 MHz
BAND SPACING	40-300 kHz	60-250 kHz	1-5 MHz
FREQUENCIES OBSERVED	200-≥1300 kHz	200-1000 kHz	10-35 MHz
DURATION	≈ 10 min.	≈ 20 min.	≈ 20 min.
OCCURRENCE PROBABILITY			
VOYAGER-1			
PRE-ENCOUNTER	0.045	≈ 0.03	< 0.01
POST-ENCOUNTER	0.016	≈ 0.03	< 0.01
VOYAGER-2			
PRE-ENCOUNTER	0.081	≈ 0.03	< 0.01
POST-ENCOUNTER	0.030		< 0.01

Table 1

Table 1 shows some banded MSA characteristics as found in a survey of events that occur in conjunction with HOM, SKR, and DAM. Chaotic MSA events are not included in Table 1, but they are more probable than banded MSA in HOM by a factor of 2–3. Occurrence probability values are for approximately six week periods centered on closest approach to the planets. Low–band MSA at Jupiter and Saturn is similar except there is a pre– and post–encounter difference in occurrence probabilities at Jupiter, but none is apparent for Saturn. The ratio of the pre– and post– encounter probabilities for both Voyagers 1 and 2 are nearly the same at Jupiter, indicating a consistent effect. Saturn events are weaker in appearance and more often single–banded. No probabilities are computed for Voyager 2 after Saturn encounter since no SKR or MSA were detected for a long period after closest approach. DAM events are rare, usually only occurring in conjunction with Io–related source B or C events.

The DAM events show a dependence on both Jovian longitude and the position of Io. Are there any dependencies for the low frequency Jovian HOM events? Figure 5 displays histograms of relative occurrence probability of Jovian banded MSA vs. CML and Io phase for each spacecraft. There appears to be no significant, consistent correlation with Io phase. Although the events are also well–distributed in Central Meridian Longitude and the peaks are not outstanding, the peaks may be significant since they are similarly located in longitude for both spacecraft, i.e., both plots show peaks in the 40° – 100° and 260° –300° ranges. This is reminiscent of the twin peaks in occurrence probability for diffuse HOM which occur slightly higher in longitude.

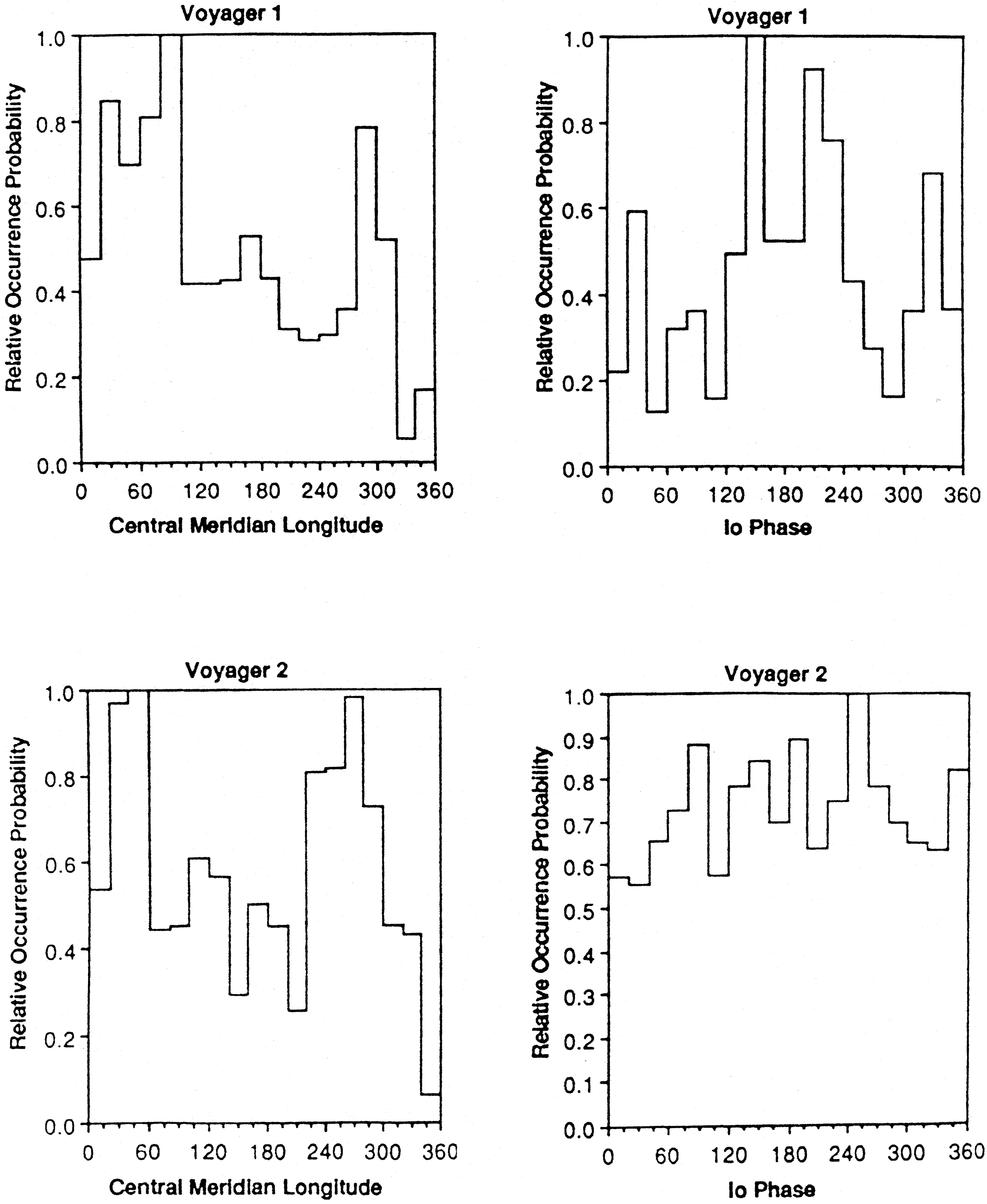

Fig. 5: Histograms of relative occurrence probability of Jovian banded MSA in HOM versus Central Meridian Longitude and Io phase for each of the Voyager spacecraft within three weeks on either side of closest approach. Ratios of minutes of MSA activity to minutes of observing time in each 20° bin were calculated and normalized to the maximum value.

3. Possible MSA sources

Table 2 summarizes four categories of MSA explanations: single source, multiple source, diffraction, or aliasing. A single source of MSA would help to explain emission in banded form, especially such properties as simultaneous turn–on and the lack of crossovers, since the multiple bands would be working in concert with each other. The periodic bands might be explained by harmonic emission with the sawtooth shape indicating a frequency cutoff which is reflected in each of the harmonics. A possible location for a single source is along the Io flux tube which is unique in terms of available energy (see upper left of MSA source possibilities diagram). On the negative side, a single source requires an isotropic emission property since MSA is observed at all longitudes and Io phases (Figure 5). This is difficult to reconcile with the Io field line emission theories which usually predict beamed emission. Explanations of banded emission in terms of harmonics have difficulty with aperiodic band spacing and bands which do not always track each other. The rapid variation of chaotic emission is also difficult to explain with a single source.

Chaotic emission seems more likely explained by multiple sources. If sources are randomly dispersed then one would often expect to see a mixture of banded events which would appear as chaotic emission. The banded events may be an indication of only a single source being in view. The sighting of multiple sources would be more probable than a single source , thus explaining the higher probability of chaotic emission. The problem is the perceived lack of clear crossovers if multiple banded emission sources are being received.

As an alternative, it may be possible to have multiple sources which are evenly distributed, such as sources associated with multiple reflections of the Alfvén wave traveling from Io to Jupiter along magnetic flux lines (Gurnett and Goertz, 1981). If the emission is in the form of consistent wide or narrow cones then there would not be a significant amount of overlap among sources and the crossovers would be minimized. One would still expect to see some crossovers within the chaotic events, however.

The banded MSA in many ways resembles a diffraction pattern, and the theory invoked by Lecacheux et al. (1981) to explain arc structures could also be applied here. In this explanation, the Io torus serves as a diffraction screen between the spacecraft observer and an MSA source causing fringe patterns reminiscent of both chaotic and banded MSA. Such a torus does not exist at Saturn, however, and diffraction would not explain: why the MSA does not occur in a regular pattern as the torus rocks in and out of the field of view of the source; the sawtooth pattern often found in the emission; and the aperiodic spacing of the bands.

The chaotic emission could possibly be explained by time aliasing involving the 6–sec sweep cycle and the 30–ms sampling time of the PRA instrument's operating mode. This would explain the rapid variation in modulation from one 6–sec sweep to the next and the periodic recurrence of modulation within a single sweep. On the other hand, aliasing does not explain banded emission since, in cases where the bands remain stable in frequency for many minutes, the source of the time modulation would also have to be stable to a factor of 10^{-3}. There is also difficulty in explaining aperiodic band spacing within a single sweep, as well as the problem of the sawtooth pattern.

MSA EXPLANATIONS

EXPLANATION	FOR	AGAINST
SINGLE SOURCE	Banded emission Harmonics with cutoff Lack of crossovers Energy in Io flux tube Simultaneous turn-on	Need isotropic emission mechanism Aperiodic band spacing Chaotic emission
MULTIPLE SOURCE	Chaotic emission Higher chaotic probability	Lack of crossovers
DIFFRACTION	Bands resemble diffraction patterns Io torus can cause diffraction	Intermittent occurrence Aperiodic band spacing No Saturn torus Sawtooth pattern
ALIASING	Chaotic emission	Banded emission Aperiodic band spacing Sawtooth pattern

Table 2

4. Summary

In summary, we have several conclusions. Some form of MSA appears in conjunction with all the known types of radio emission from Jupiter and Saturn indicating that it may be a pervasive phenomenon in the radio spectrum. Similarities in the HOM and MSA occurrence probabilities as well as the upper frequency envelope occurrence tendencies of MSA in connection with the SKR and DAM emission imply a direct relationship of the modulation with the unmodulated emission at the same frequencies, i.e. it is not the result of a separate radio source. Any theories will need to explain some puzzling characteristics: aperiodically spaced emission peaks with frequency; the "sawtooth" modulation pattern of the peaks; pre– and post–encounter differences in the occurrence probability of MSA appearing in conjunction with Jovian MSA; the apparent lack of crossovers in multiply banded emission; etc. As yet, no completely satisfactory theory has been found.

Acknowledgements: The authors wish to acknowledge Tomas Arias, Roeland Hammerschlag, and Michael Desch for their initial work in the analysis and interpretation of MSA events. Further analysis would have been impossible without the assistance of Michael Kaiser in making the data available and overcoming data reduction problems. The work of D. H. Staelin is supported through NASA contract NAS 5–28410 and NASA grants NAGW 373 and NAG 5–537.